


ORIGINAL RESEARCH

Emergency Medical Services

Potentially survivable fatal vascular access hemorrhage with tourniquet use: A post-mortem analysis

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Abstract

Background: The US military has prioritized battlefield hemorrhage control. Researchers credit tourniquet use, and a novel trauma care training program, with saving 1000–2000 lives in Iraq and Afghanistan. The Stop the Bleed campaign translates these lessons learned to the public. This is the first analysis of the potential impact of this newfound knowledge about tourniquet use for extremity fatal vascular access hemorrhage in a civilian population. Fatal vascular access hemorrhage includes bleeding from arteriovenous fistulas and grafts used for hemodialysis and central venous catheters.

Methods: This is a retrospective study of decedent records. We selected Maryland death records from 2002–2017 using the following search terms: “graft,” “shunt,” “fistula,” “dialysis,” and “central venous catheter.” The records were analyzed for potential survivability with a checklist of military criteria modified for a civilian population. Suicides were excluded. Two reviewers independently classified the deaths as either potentially survivable or non-survivable, and a third reviewer broke ties.

Results: There were 111 deaths included in the final analysis. Ninety-two of the 111 decedents had potentially survivable extremity fatal vascular access hemorrhage. The remaining 19 records were excluded, because they did not have extremity hemorrhage. Zero decedents had hemorrhage deemed to be non-survivable with prompt tourniquet application.

Conclusion: This study identified 92 Maryland extremity fatal vascular access hemorrhage decedents who potentially could have survived with tourniquet use—an average of 6 per year. These results suggest the need for further epidemiology investigation, as well as exploration of the risks and benefits of teaching and equipping vascular access patients and their caregivers to use tourniquets for life-threatening bleeding.

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1 | INTRODUCTION

During the recent wars in Afghanistan and Iraq, the US military prioritized hemorrhage control for battlefield survival and researchers credit tourniquet use, coupled with a novel education program for medical and non-medical personnel, with saving 1000–2000 lives during these wars.^{1,2} The Stop the Bleed campaign is a public–private effort launched by the White House in 2015 that aims to translate hemorrhage control techniques learned on the battlefield to the American public.³ Evidence is building to show that civilians suffer extremity hemorrhage that can be survivable with prompt tourniquet placement, and out-of-hospital civilian tourniquet application saves lives.^{4,5} Previous literature has described fatal vascular access hemorrhage, with an appropriate focus on prevention. However, there has not been a specific analysis of the potentially life-saving role of prompt limb tourniquet use for otherwise fatal extremity vascular access hemorrhage.^{6–8} Fatal vascular access hemorrhage includes bleeding from arteriovenous fistulas and grafts used for hemodialysis, and central venous catheters.

Roughly 468,000 patients in the United States are on dialysis for renal failure.⁹ Many of these patients have extremity arteriovenous fistulas or grafts, which are high-pressure, high-flow access points, that can cause catastrophic bleeding when disrupted. Life-threatening hemorrhage from these extremity arteriovenous fistulas and grafts structures would be potentially survivable with the use of a limb tourniquet.

A prior study evaluated potentially survivable hemorrhage in a civilian population using medical examiner data, and identified a number of patients with fatal vascular access hemorrhage who may have survived with prompt tourniquet use.⁴ This study uses Maryland Medical Examiner data and criteria originally developed to analyze battlefield deaths to assess the potential impact of tourniquet use on the survivability of extremity vascular access hemorrhage.¹⁰

2 | METHODS

This is a retrospective study of civilian decedent records. The Uniformed Services University Institutional Review Board determined this study did not meet the criteria defining human subjects research (Protocol MEM-91-9116). Maryland's Office of the Chief Medical Examiner (OCME) is a centralized, statewide agency that, "investigate(s) deaths from injury, homicide, suicide, under unusual or suspicious circumstances, or when a person is not attended by a physician."¹¹ Deaths are reported to the OCME from all settings including in-hospital, out-of-hospital, and nonmedical settings.

In April, 2018, we searched the OCME database from 2002–2017 using the following terms to identify decedents with possible fatal vascular access hemorrhage: "graft," "shunt," "fistula," "dialysis," and "central venous catheter." We excluded decedents younger than 18 years old and suicides. The search produced 285 incomplete, abbreviated records called abstracts (Figure 1). Two board-certified emergency physicians served as abstract reviewers. The 2 reviewers independently coded each abstract as either green or red to determine if the abstract should be included in the study and the full decedent

The Bottom Line

The Stop the Bleed Program translates success the military has had in saving thousands of lives in Iraq and Afghanistan to the civilian environment. This study looked at how the use of tourniquets for extremity fatal vascular access hemorrhage could potentially save lives. This retrospective study found that 92 people (average 6 per year) in Maryland suffering from fatal vascular access hemorrhage could be saved by use of tourniquets.

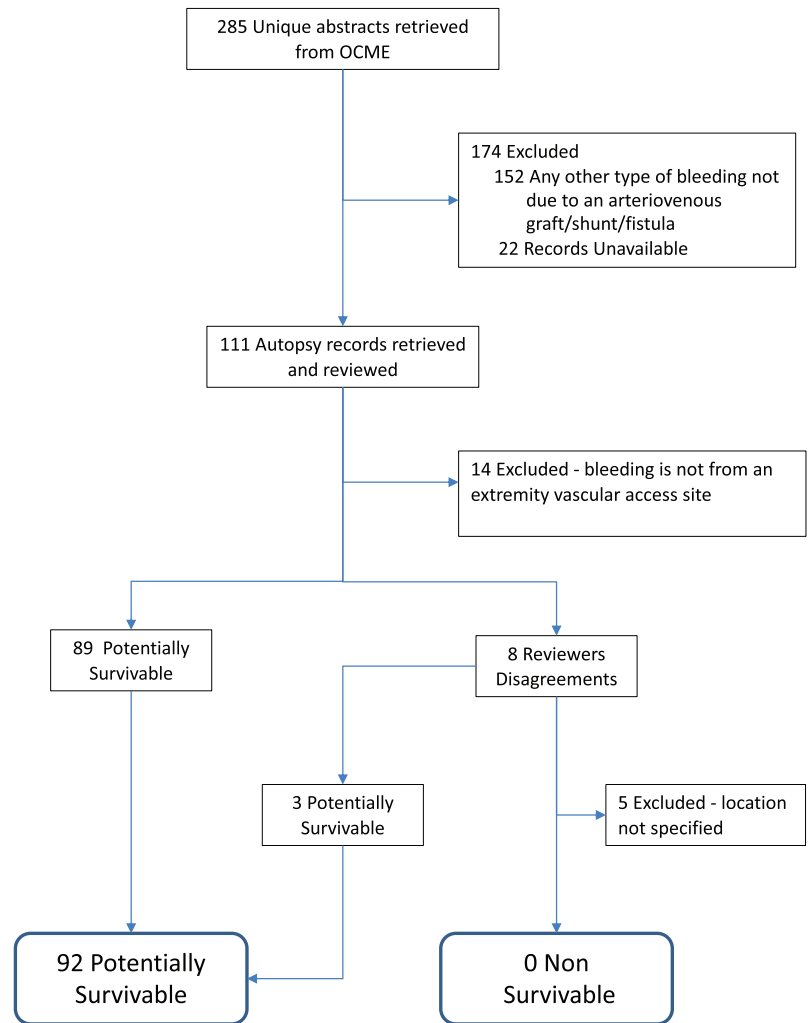
record retrieved. A case was coded as green if it involved any extremity vascular access hemorrhage, or if the reviewer could not tell if bleeding occurred from an extremity vascular access site. A case was coded red if it did not involve any bleeding from an extremity vascular access site, or if it was a suicide. Any case receiving 1 or 2 green scores was included for further analysis, and any case receiving 2 red scores was eliminated from the study.

After this abstract screening, we obtained the complete available decedent records for the remaining 111 cases. The records were a mixture of complete autopsies, as well as other official medical examiner determinations that did not involve a complete autopsy, such as partial autopsies and OCME inspections. In these types of reports, the medical examiner determines a cause of death with less information than would be available in a complete autopsy. This type of determination is used when a more obvious cause of death is apparent, and for a manner of death that is accidental or natural.

The 2 reviewers above, plus another board-certified emergency physician and a board-certified trauma surgeon reviewed the 111 full records. The records were distributed in batches to the reviewers, so that no 2 reviewers reviewed all the same cases. Another board-certified emergency physician served as a tie-breaker. Each reviewer used a checklist with a modified version of the criteria originally developed by Eastridge and colleagues for a military survivable death analysis.¹⁰ The criteria were adapted for a civilian population and used in a 2018 analysis of potentially survivable extremity hemorrhagic death (Table 1).⁴ For a decedent who suffered an extremity fatal vascular access hemorrhage, the checklist was used to determine if there were other severe conditions or injuries that would not be survivable under any circumstance, including with prompt bleeding control. As examples, the checklist screened for thoracic airway transections and cardiac injuries with defects $\geq \frac{1}{2}$ inch in length, which we assumed would not be survivable even with optimal care. Reviewers were instructed that the extremity bleeding must be from a vascular access site for this study.

3 | RESULTS

Of the 111 full records reviewed, 92 (83%) were determined to be potentially survivable with prompt tourniquet placement, 19 (17%)

FIGURE 1 Study enrollment

were excluded because the decedent did not have fatal vascular access hemorrhage of an extremity or the bleeding site could not be determined, and 0 were determined to be non-survivable. Eight of the cases (7%) had reviewer disagreements and required a third review to make a final determination. Of these, 3 were determined to be potentially survivable, and 5 were excluded because the bleeding site could not be determined definitively. Due to rare reviewer disagreement, percent agreement was assessed descriptively. The reviewers agreed 89% of the time when reviewing the 285 abstracts, and a Cohen's kappa test of both reviewers for all cases found that $\kappa = 0.77$.

A summary of patient demographic data and location at onset of hemorrhage is presented in Table 2. Seventy-seven (84%) of decedents in the study were 50 years old or older. Sixty-eight (74%) of the deaths occurred at home, 17 (19%) occurred in a nursing or assisted living facility, and an additional 5 (5%) also occurred completely outside a medical environment, such as in a vehicle or in a park.

4 | DISCUSSION

This study is the first epidemiologic analysis of its kind to assert the potential for tourniquet use to reduce mortality from fatal extrem-

ity vascular access hemorrhage. During the 15-year time period of this study, we identified 92 vascular access hemorrhage decedents who could have potentially survived with prompt tourniquet placement. This is ≈ 6 patients per year in Maryland that has a population of ≈ 6 million people. Furthermore, this analysis did not identify any fatal vascular access hemorrhage deaths who definitely would not have survived if a tourniquet had been placed in time.

This study expands the findings of a 2018 analysis of hemorrhagic deaths from extremity bleeding.⁴ That study used the modified Eastridge criteria to analyze medical examiner data, and concluded that ≈ 480 lives in the United States might be saved annually with prompt tourniquet placement.⁴ During this study, the authors noted a group of 54 cases associated with vascular access. They excluded 35 (65%) of these cases from that study, because the cases lacked the full autopsies required by the 2018 study protocol.⁴ Many of the vascular access related deaths have an obvious cause of death and therefore do not undergo full autopsy by a medical examiner.

Although the Stop the Bleed campaign is often associated with intentional mass casualty incidents, it is intended to benefit everyone from everyday causes of bleeding. Indeed, the Centers for Disease Control list trauma as the leading cause of death for people between the ages of 1–44 years, and hemorrhage is a leading cause of

TABLE 1 Reviewer criteria

Element	Criteria
Inclusion	Is there any bleeding from an extremity Is the manner of death not suicide
Exclusion	Physical dismemberment
	Catastrophic brain injury (any of the following)
	Brain evisceration
	Transcranial penetrating or disruptive blunt brain injury involving deep nuclei or critical vasculature
	Brain stem injury
	Cervical cord transection (above cervical level 3)
	Airway transection within thorax
	Cardiac injury $\geq \frac{1}{2}$ inch
	Thoracic aorta injury
	Pulmonary artery injury
	Hepatic avulsion
	Catastrophic abdominopelvic injury
	Characterized by lower extremity amputations with open pelvis and large soft tissue loss/traumatic hemipelvectomy
	Evidence of sepsis
	Significant pulmonary embolus (\geq segmental)

TABLE 2 Demographics

Variable	Potentially survivable (n = 92)
Sex, n (%)	
Female	43 (47)
Male	49 (53)
Race or ethnic group, n (%)	
African American	74 (80)
White	14 (15)
Other	4 (4)
Age, y, mean (SD)	65 (\pm 14)
Age Category, n (%)	
30–39 y	5 (5)
40–49 y	8 (9)
50–59 y	18 (20)
60–69 y	22 (24)
70–79 y	23 (25)
80–89 y	14 (15)
Unkown	2 (2)
Patient location at the time of fatal hemorrhage, n (%)	
Home	68 (74)
Hospital	2 (2)
Nursing home/assisted living	17 (19)
Other (vehicle, park, street)	5 (5)

preventable traumatic death.^{12–14} However, the unique vascular access patients in this study, who often have atraumatic bleeding, may benefit even more than the general public from targeted outreach to prepare and equip them to stop life-threatening bleeding. Furthermore, although it can be challenging to educate and equip the general public at home, nearly 1 in 5 of the deaths in this study occurred in nursing and assisted living facilities. Special outreach to these locations may also be beneficial.

Two of the Stop the Bleed campaign's objectives are that the general public will know how to stop life-threatening bleeding and have access to private and public bleeding control kits.¹⁵ Our study showed that 79% of the fatal vascular access hemorrhage occurred in the home or community, and other studies have similarly reported \approx 80% of fatal vascular access hemorrhage in these settings with 44% of fatal vascular access hemorrhage decedents ultimately dying at home.^{7,16,17} Currently, multiple sources recommend direct pressure with a finger to control vascular access bleeding, and either recommend against tourniquet use or state that there is no agreement about recommending tourniquets.^{6,8} It may be reasonable to ensure that patients with extremity vascular access and their family members are taught how to use tourniquets to stop life-threatening bleeding, that they are equipped with bleeding control supplies, and that they understand the appropriate indications for direct pressure and tourniquet placement.

Likewise, it may be beneficial for dialysis center staff and emergency medical services (EMS) providers to understand when and how to use tourniquets in this unique group of patients. In addition, Stop the Bleed training could be instituted for staff, patients, and family members at hemodialysis centers. EMS adoption of Stop the Bleed techniques and tourniquet use has been growing; however, it is not ubiquitous.¹⁸ Although a Minnesota study showed that 7% of 125 tourniquet applications were for uncontrolled hemodialysis fistula bleeding, it is likely that at least some out-of-hospital Stop the Bleed training may not address the nuanced considerations of vascular access hemorrhage.¹⁹

This study identifies lives that likely could have been saved by prompt hemorrhage control with a tourniquet. It does not provide evidence about people's ability to delineate life-threatening from non-life-threatening bleeding, although there is some evidence that the public can make this distinction.^{20,21} Although tourniquet placement in the general population is considered reasonably safe for short duration applications, inappropriate tourniquet placement could cause unique harm in a vascular access population that depends on hemodialysis.²² However, in 1 retrospective case series of 26 patients with potentially fatal vascular access hemorrhage, only 16% had tourniquet application in the ED, but all patients required emergency operating room intervention, making it unlikely that the tourniquet itself resulted in the need for surgical repair.²³ Eighty-five percent of patients in this study had successful access salvage in the operating room.²³

Direct pressure, which can be supplemented by topical hemostatic agents or reversing systemic coagulopathy, will control most bleeding and should be used preferentially when possible.^{24,25} However, tourniquets may prove life-saving in cases of exsanguinating hemorrhage;

when someone is alone and life-threatening bleeding occurs; or when bleeding may not be controlled adequately with direct pressure.^{24,25} Any instructions to patients or caregivers that recommend tourniquet use would need to be carefully crafted to balance the life-saving potential of tourniquets with the potentially serious adverse consequences of inappropriate application near vascular access sites.

This study has several limitations. It relies solely on medical examiner data, which may have underestimated the prevalence of potentially survivable vascular access hemorrhage. If a certifying physician reported vascular access hemorrhage as a “natural” death, there would not necessarily be a record in the medical examiner’s system. Furthermore, this study does not consider morbidity from bleeding, such as the duration of ICU stays, need for transfusion, or other potential harms that might be lessened with prompt bleeding control. These factors could contribute to a conservative bias in our findings. This bias may underestimate the potential benefit of tourniquet use. The US Renal Data System’s Annual Data Report reported that 102,188 end-stage renal disease patients died in 2016.²⁶ Fatal vascular access hemorrhage has been estimated in multiple studies to cause ≈1% of deaths in US patients on hemodialysis.^{7,27} Next, although our analysis did not detect it, it is very likely that some of these patients with isolated extremity hemorrhage would not have survived even with prompt tourniquet placement. End-stage renal disease patients, in particular, often have numerous co-morbid conditions, and even a small amount of hemorrhage may not be survivable in the setting of coronary disease, ongoing infection, or other serious medical problems. In addition, although a number of studies have demonstrated the public’s ability to apply tourniquets successfully, there are no studies specifically looking at the end-stage renal disease population that would likely be more debilitated than the general population.^{20,28–30} This study did not consider non-tourniquet methods of hemorrhage control, like direct pressure, which might have also been life-saving in some of the cases reviewed. Although blinded to one another’s scores, the reviewers did know the study objective that could have introduced bias. Finally, 22 records selected for review were not available.

5 | CONCLUSIONS

This study is the first epidemiologic analysis of its kind to assert the potential for tourniquet use to reduce mortality from fatal vascular access hemorrhage. This study identified 92 Maryland decedents in a 15-year period who died from fatal vascular access hemorrhage who potentially could have been saved by tourniquet use—an average of 6 per year. These results suggest the need for further investigation of the epidemiology of fatal vascular access hemorrhage, as well as exploration of the risks and benefits of teaching and equipping vascular access patients and caregivers to use tourniquets for life-threatening bleeding.

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AUTHOR CONTRIBUTIONS

Study conception and design: CG, LER, MA, and MJL; Acquisition of data: CG, LER, MA, MJL, NC, LT, and JP; Analysis and interpretation of data: CG, LER, MA, MJL, NC, LT, JP, and TER; Drafting of article: CG, LER, MA, MJL, NC, LT, JP, and TER; Critical revision: CG, MJL, NC, LT, JP, and TER. CG takes final responsibility of the article.

CONFLICTS OF INTEREST

CG has a patent pending for “Tourniquet and Methods of Use.” The remaining authors declare no conflicts. The views expressed in this article are those of the authors, and do not reflect official policy of the Uniformed Services University, Department of the Army, Department of the Navy, Department of the Air Force, Department of Defense, or the US Government.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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